RESEARCH HIGHLIGHTS

Technical Series 00-124

COST-EFFECTIVE CONCRETE REPAIR: RESEARCH, INVESTIGATION, ANALYSIS, AND IMPLEMENTATION

Introduction

There are a variety of ways that concrete can deteriorate and a variety of contributing causes. There are also a variety of ways of dealing with any one type of deterioration, the correct selection of which is as much a financial/operational issue as a technical performance issue. The technical reasons and means for repairing concrete have been the topic of considerable research over the past 30 years. Technical advances in materials, demolition, repair and protection techniques have far outpaced the question of life-cycle costing and cost-benefit assessment as related to the same repair.

This project is unique in that its intended audience is property owners and managers, rather than engineers and researchers. The final report examines the possibility of different repair strategies to suit the needs of different owners, and provides examples using repair cost data and analytical costing tools that owners can use to make economic assessments. The report provides a road map that owners can follow as they begin to tackle repair of their concrete.

Research Program

The need to understand what causes concrete to deteriorate and to determine the action needed to rectify the problems has been the impetus for extensive research over the past 30 years in Canada. One of the goals of this work was to reduce the vast amount of information already available on concrete durability and repair to a readily usable summary that owners can reference when confronted with poorly performing concrete. The research program consisted of a literature review of approximately 80 documents.

Results

The report, "Cost-Effective Concrete Repair: Research, Investigation, Analysis, and Implementation", reviews the characteristics needed to produce durable concrete, the factors that cause deterioration, common and newer test methods to evaluate the state of the concrete, and common repair techniques and cost issues associated with concrete repair practices. The report is organized into four chapters and nine appendices:

Chapter 1	Concrete Deterioration
Chapter 2	Test and Evaluation Procedures
Chapter 3	Repair Alternatives and Cost Implications
Chapter 4	Repair and Protection Techniques
Appendix A	Research into Concrete Durability
Appendix B	Durability and Construction Standards
Appendix C	Durability and Concrete Composition
Appendix D	Freeze-Thaw Damage and Scaling
Appendix E	Electrochemical Corrosion
Appendix F	Design, Durability and Safety
Appendix G	Life-Cycle Cost Analysis
Appendix H	Cathodic Protection
Appendix I	Typical Costs for Repair and Protection of Concrete

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Some of the key points made in each chapter are outlined below:

Concrete Deterioration

The most prevalent forms of deterioration are: scaling, disintegration, cracks (narrow and wide), leaching and efflorescence, and delamination and spalling (salt-induced and carbonation-induced).

Concrete deteriorates both because of the way it is produced (design and/or construction) and the way it is used (environment and/or load issues). To properly repair concrete, it is necessary that the proper fault be addressed and that the subsequent resolution of the fault addresses both production and use.

It has been suggested that another contributing factor to the occurrence of distress may be the design criteria stipulated in building codes of different years, particularly the change in approximately 1970 to limit-states design, which allowed for the design of thinner members. However, the occurrence of concrete deterioration has also prompted other more positive changes to codes and good construction practices, including: the use of epoxy-coated reinforcing steel; the use of air-entrained concrete; an increase to a two-percent slope to drains; and the requirement for minimum protection through the application of waterproofing, sealers and more durable concrete suiting the exposure conditions.

Test and Evaluation Procedures

The test performed to evaluate reinforced concrete in buildings are summarized in Table 1.

A visual examination should always be the first step in evaluating the existing conditions. The other tests or evaluation procedures to be employed will depend on the distress observed, as indicated in Table 1.

Repair Alternatives and Cost Implications

Eight steps are identified as milestones in determining repair needs and establishing a repair strategy:

Step 1 Identify the problem and the cause of the observed deterioration.

Step 2 Define the objectives of the repair, as well as any constraints that would affect the implementation of the repairs.

Step 3 It is recommended (but not always necessary) that the owner retain the services of an expert consultant. The owner and consultant must come to a mutual understanding of the objectives and the constraints, including financial, operational and technical considerations.

Step 4 Based on the agreed objectives, the consultant will develop an evaluation protocol.

Table 1: Test and Evaluation Procedures Related to Deterioration and Primary Causes

● Usual
❍ Occasional

	Examination/Tests									Primary Cause(s)											
Distress	Visual Unaided	Visual Microscopic	Hammer/Chain Sounding	pH	Electro-potential	Cover meter	Chloride Content	Absorption	Special Non-Destructive Tests	Moisture	Chloride	Sulphate	Carbon Dioxide and Moisture	Unprotected Embedded Metals	Misplaced Reinforcing	Thermal Stress	Load	Deleterious Aggregate	Initial Shrinkage	Poor Air Void Distribution	Poor Placing/Curing/Finishing
Scaling and Pop-outs	●	●						●		●	●							❍		●	❍
Disintegration	●	●							❍	●		❍						●			
Wide Crack	●								❍						❍	❍	●				
Narrow Crack	●								❍						❍				●		●
Leaching & Efflorescence	●							❍		●	●	❍					❍		❍		
Reinforcing Steel Corrosion	●		●	●	●	❍	●	❍		●	●		❍	●	❍						
Post-Tension Cable Corrosion	●								●	●	●			●							
Carbonation	●		●	●				❍		●	●		❍		❍						❍

Step 5 The consultant must perform the evaluations and the owner must determine financing options.

Step 6 The owner and consultant should jointly review the completed technical assessment and the implications of the alternative courses of action in order to decide which repair is most appropriate for their situation.

Step 7 The specifications and contract documentation for the repairs should be prepared.

Step 8 Prequalified contractors should be invited to bid and the selected contractor should complete the repairs.

Owners are cautioned against accepting advice from their consultants that depicts only one repair alternative. Alternative repair options are available in virtually all cases of failed or deteriorated concrete, and each alternative repair option has a different cost associated with it. It is therefore necessary to link engineering assessments of the evidence and cause of distress with economic assessments of the financial feasibility of the alternative repair strategies. This economic analysis is accomplished by using one or a combination of three common types of economic analysis procedures:

Cost-Benefit Analysis: a comparison of the known costs of one or more repair alternatives with the expected benefits obtained from that repair over a set period of time.

Compliance Analysis: a comparison of one or more repair alternatives of known cost against a set of prescribed objectives.

Life-Cycle Cost Analysis: a comparison of the total cost of design, remediation, maintenance and subsequent iterations of that process over the deemed life of the structural element for one or more repair alternatives.

Repair and Protection Techniques

Historically, concrete was repaired by removal of the affected area and replacement with similar concrete. The development of repair materials for concrete has been remarkable over the last decade; repair material products number in the hundreds and include crack repair materials, specialty cements and repair systems with reinforcing fabrics, meshes or fibres. The majority of the most-used products, however, can be broadly grouped by their mode of use into:

Replacement Materials: normal portland cement concrete patches, latex-modified concrete, epoxy-modified concrete, magnesium-phosphate cements;

Crack Fillers and Adhesives: chemical crystalline; chemical gels;

Surface Stabilizers: micro silicas, impregnated polymethylmethacrylate.

Once the repair material has been selected for the application, the method of application likely governs the durability of the repair. Factors that can be controlled in the design of the repair include:

Removal Techniques: chipping, high-pressure water;

Repair Geometry: the shape of the edge of the repair can be V-shaped, square or dovetail, feather edged;

Surface Preparation: high-pressure water, chemicals, abrasive blasting;

Bonding: bonding agents or adhesives like cement slurry or epoxy, relying on the properties of the patch materials.

Once the concrete is repaired, it will often require protection against the aggressive environment that first initiated the distress. This is typically accomplished through the use of waterproofing membranes or sealers. The application of cathodic protection to suspended parking garage slabs is also available as a means of providing protection against further corrosion-induced delamination and spalling. Epoxy coating of reinforcing steel exposed by removal of deteriorated concrete is also sometimes performed in an effort to electrically isolate the reinforcing steel that corroded and caused delamination.

There is very little documentation on the performance of remedial work. However, some studies suggest that the commonly employed methods of repair can be adequate if ongoing maintenance is undertaken.

Author's Follow-up Note, September, 2000: *Since the early 1990s when the study was complete, the author notes that there is an increased frequency of suspended garage slab replacement or, at least, replacement of the upper 75 to 100 mm, including top reinforcement. This is in response to apparent premature failure of conventional repairs after only 12 to 15 years. While each site would have specific conditions that would control life of repairs, the trend to reduced life of conventional repairs must be considered in the overall economic assessment of repair options.*

Implications for the Housing Industry

The report, "Cost-Effective Concrete Repair: Research, Investigation, Analysis, and Implementation", is a compilation of the extensive research work undertaken by CMHC. It is intended for use by building owners and managers in their efforts to establish a rational course of action for repair of deteriorated concrete. The body of the report provides the reader with a general understanding and appreciation of the issues surrounding concrete repair. The appendices provide more comprehensive information that is useful background for property owners and managers when they discuss repair options with their consultants.

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A full report on this project is available from the Canadian Housing Information Centre at the address below.

Housing Research at CMHC

Under Part IX of the *National Housing Act*, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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